PARASITES OF WHITE CRAPPIE (*POMOXIS ANNULARIS*) IN THE CONCHO VALLEY OF WEST-CENTRAL TEXAS

A Thesis

Presented to the

Faculty of the College of Graduate Studies and Research

Angelo State University

In Partial Fulfillment of the

Requirements for the Degree

MASTER OF SCIENCE

by

BLAKE PRICE THORNTON

May 2021

Major: Biology

PARASITES OF WHITE CRAPPIE (*POMOXIS ANNULARIS*) IN THE CONCHO VALLEY OF WEST-CENTRAL TEXAS

by

BLAKE PRICE THORNTON

APPROVED:

Dr. Nicholas Negovetich

Dr. Ned Strenth

Dr. Ben Skipper

Dr. Joel Carr

May 2021

APPROVED:

Dr. Micheal W. Salisbury
Dean, College of Graduate Studies and Research

DEDICATION

I dedicate this thesis to my wife Teagan and to my parents for their constant support throughout my academic career.

ACKNOWLEDGMENTS

I would like to thank Dr. Negovetich for his support and direction throughout my time at ASU. He has taught me to think critically and has helped sharpen my skills as a biologist. I would like to thank Dr. Strenth for his support and expertise, especially in the fields of scientific writing and limnology. I would like to thank Dr. Skipper for his support and assistance with map making and ecology. I would like to thank Dr. Carr for his support and expertise. I also want to thank Lynn Wright, Charles Cruz and John Ingle for their teaching and support. Without them, and others at Texas Parks and Wildlife Department Inland Fisheries, I would not have obtained the valuable field experience I did throughout my education. Thank you to Texas Parks and Wildlife Department Inland Fisheries San Angelo for the donation of white crappie for this project, as well as allowing me to use their facility to age the donated fish.

ABSTRACT

During the fall and winter of 2019, trap net surveys were conducted on the South Concho River, Lake Nasworthy, O.C. Fisher Reservoir, and Twin Buttes Reservoir in San Angelo, TX. The trap net surveys were conducted in conjunction with Texas Parks and Wildlife Department Inland Fisheries San Angelo, who were interested in estimating fish population size and structure in the 4 aquatic systems. The goal of the surveys reported here was to collect and report the parasites present in white crappie (*Pomoxis annularis*) in the Concho Valley. The fish (n=113) were frozen upon collection and necropsied in the summer of 2020. Additionally, the otoliths were removed and analyzed to compare age-specific rates of infection. Four parasite species were recovered: *Cleidodiscus* sp., *Camallanus oxycephalus*, *Contracaecum* sp., and *Argulus longicaudus*. The intensity and prevalence of each parasite species was reported and compared between aquatic systems. The prevalence of *Cleidodiscus* sp. was highest in the South Concho River, the prevalence and intensity of *Camallanus oxycephalus* was highest in Lake Nasworthy, and the prevalence and intensity of *Contracaecum* sp. was highest in O. C. Fisher Reservoir. No downstream accumulation of parasite prevalence or intensity was observed.

TABLE OF CONTENTS

DEDICATION iii

ACKNOWLEDGMENTS iv

ABSTRACT v

LIST OF TABLES vii

LIST OF FIGURES viii

INTRODUCTION 1

METHODS 4

Study Sites 4

Data collection 5

RESULTS 8

DISCUSSION 11

CONCLUSION 15

LITERATURE CITED 17

APPENDIX 22

VITA 38

LIST OF TABLES

Table I. Reported parasite species of *Pomoxis annularis* in Texas (Mayberry, 2000) and location in infected hosts. N.R. = Not Reported. 22

Table II. The number of nets set and *Pomoxis annularis* collected and donated from each body of water. 23

Table III. Number of *Pomoxis annularis* per age class from Lake Nasworthy (NW), O. C. Fisher Reservoir (OC), Twin Buttes Reservoir (TB), and the South Concho River (SC). 23

LIST OF FIGURES

Figure 1. Map of the primary bodies of water in Tom Green County, TX............................ 24

Figure 2. Map of the 4 lakes and reservoirs of the North and South Concho Rivers in San Angelo, TX. 25

Figure 3. Mean (±SE) *Pomoxis annularis* age for Lake Nasworthy (NW), O. C. Fisher Reservoir (OC), Twin Buttes Reservoir (TB), and the South Concho River (SC)................ 26

Figure 4. Mean (±SE) relative weight (Wr) of *Pomoxis annularis* for Lake Nasworthy (NW), O. C. Fisher Reservoir (OC), Twin Buttes Reservoir (TB), and the South Concho River (SC). 26

Figure 5. Mean relative weight for *Pomoxis annularis* by age for Lake Nasworthy (NW), O. C. Fisher Reservoir (OC), Twin Buttes Reservoir (TB), and the South Concho River (SC). 27

Figure 6. The length (mm) and age of the *Pomoxis annularis* hosts were correlated (R^2 = 0.74). 28

Figure 7. Monogenean prevalence of *Pomoxis annularis* for Lake Nasworthy (NW), O. C. Fisher Reservoir (OC), Twin Buttes Reservoir (TB), and the South Concho River (SC), with bootstrapped 95% confidence intervals. 28

Figure 8. Monogenean prevalence by host age for Lake Nasworthy. Prevalence was highest at age 0, and lowest at age 3. Bootstrapped 95% confidence intervals were not calculated because of the small sample size within each age category.. 29

Figure 9. Monogenean prevalence by host age for the South Concho River. Prevalence was 1.0 for ages 1-5, and was lowest at age 0. Bootstrapped 95% confidence intervals were not calculated because of the small sample size within each age category. 30

Figure 10. Monogenean prevalence by host age for Twin Buttes Reservoir. Prevalence was highest at age 2, and lowest at age 4. Bootstrapped 95% confidence intervals were not calculated because of the small sample size within each age category. 31

Figure 11. *Camallanus oxycephalus* prevalence for *Pomoxis annularis* in Lake Nasworthy (NW), O. C. Fisher Reservoir (OC), Twin Buttes Reservoir (TB), and the South Concho River (SC), with bootstrapped 95% confidence intervals... 32

Figure 12. Mean (±SE) intensity for *Camallanus oxycephalus* in Lake Nasworthy (NW), O. C. Fisher Reservoir (OC), Twin Buttes Reservoir (TB), and the South Concho River (SC). Intensity was highest for individuals from Lake Nasworthy and lowest from individuals from Twin Buttes Reservoir. This parasite was not detected in O. C. Fisher Reservoir. 33

Figure 13. *Camallanus oxycephalus* prevalence for *Pomoxis annularis* from Lake Nasworthy. Bootstrapped 95% confidence intervals were not calculated because of the small sample size within each age category. 34

Figure 14. *Camallanus oxycephalus* mean intensity for *Pomoxis annularis* from Lake Nasworthy. 34

Figure 15. *Contracaecum* sp. prevalence for *Pomoxis annularis* in Lake Nasworthy (NW), O. C. Fisher Reservoir (OC), Twin Buttes Reservoir (TB), and the South Concho River (SC), with bootstrapped 95% confidence intervals. 35

Figure 16. *Contracaecum* sp. mean intensity (±SE) for *Pomoxis annularis* in Lake Nasworthy (NW), O. C. Fisher Reservoir (OC), Twin Buttes Reservoir (TB), and the South Concho River (SC). 36

Figure 17. *Contracaecum* sp. prevalence for *Pomoxis annularis* from Twin Buttes Reservoir. Bootstrapped 95% confidence intervals were not calculated because of the small sample size within each age category. 37

INTRODUCTION

White crappie (*Pomoxis annularis*) are small (length <550 mm, weight <2700 g) freshwater fish belonging to the family Centrarchidae and are native to Texas. *Pomoxis annularis* are characterized by possessing six dorsal fin spines, body pigmentation in vertical bands, and the length of the dorsal fin base less than the distance from its origin to the margin of the eye (Hubbs et al., 2008). *Pomoxis annularis* are an important recreational sportfish in the state of Texas, and are the third most targeted species by Texas anglers after bass and catfish. *Pomoxis annularis* have been periodically stocked in West Texas lakes. According to Texas Parks and Wildlife Department, Twin Buttes Reservoir and Lake Nasworthy last received *P. annularis* fingerlings in 1972; O. C. Fisher Reservoir most recently received fingerlings in 2015, with previous stockings in 2005, 1972, and 1969 (tpwd.texas.gov).

As with most freshwater fishes, *P. annularis* tend to vary in their habitat and diet preferences with age. *Pomoxis annularis* fry feed on copepods, rotifers, and algae before switching to planktonic insects at around 120 mm in length (Crawley, 1954; Burris, 1956; Edwards, 1982). At around 150 mm in length, *P. annularis* begin to feed almost exclusively on small fishes (Crawley, 1954). Juvenile *P. annularis* prefer habitats consisting of shallow bays and flooded terrestrial vegetation, while adults prefer habitats consisting of a rocky substrate, submerged trees and wood, aquatic vegetation, brush, and large rocks or boulders (Hansen, 1965; Kaczka and Miranda, 2014).

Journal of Parasitology

Pomoxis annularis are known to host many different species of parasites (Mayberry et al. 2000), each requiring specific environmental variables and hosts to complete their life cycle. Exposure to various habitat types and prey items by *P.annularis* may influence or explain the relationship between the parasitic diversity and the length and age of the fish.

White crappie in Texas are known to host a variety of parasitic organisms including species in the class Eucestoda (n=2), class Trematoda (n=9), phylum Nematoda (n=4), phylum Acanthocephala (n=2), and subphylum Crustacea (n=3). Mayberry et al. (2000) provide an extensive literature review of the parasites and vertebrate hosts of Arizona, New Mexico, and Texas. They reported 20 species of parasites infecting *P. annularis* in Texas (Table 1). Their list does not include any reported parasites for *P. annularis* in Arizona or New Mexico.

Most studies examining the parasites of white crappie in Texas have taken place in North and East Texas. The Concho Valley (50,000 km^2) is in West-Central Texas. It consists of 13 counties, including Coke, Concho, Crocket, Irion, Kimble, Mason, McCullough, Menard, Reagan, Schleicher, Sterling, Sutton, and Tom Green Counties. The 4 bodies of water examined during this study reside in Tom Green county (Figure 1).

Little is known about the parasites infecting fishes in the Concho Valley. In fall and winter 2019, Texas Parks and Wildlife Department Inland Fisheries Division (TPWDIF) performed trap net surveys to determine population size and size structure of *P. annularis* (Wright, 2019). Fish were donated so that this study could be performed. The overall goal was to report on the parasites infecting *P. annularis* in these 4 aquatic systems. Comparing the parasite communities of these systems might reveal differences in the overall health and productivity of these systems. Additionally, Twin Buttes Reservoir, Lake Nasworthy, and the

South Concho River are linearly connected; the potential downstream accumulation of parasite prevalence and intensity from one body of water to the next is possible (Blasco-Costa et al., 2013).

METHODS

Study Sites

The primary river system in the Concho Valley is the Concho River. Along tributaries of this river are 3 reservoirs: Twin Buttes, O. C. Fisher, and Lake Nasworthy. These 3 reservoirs were established for flood control, irrigation, drinking water access, and recreational purposes. Today, they are managed as recreational fisheries, and provide opportunities for anglers to target a wide variety of fish species. The South and Middle Concho River flow north and west, respectively, into Twin Buttes Reservoir, a 9,080-acre reservoir located southwest of San Angelo, TX. This reservoir is characterized by flooded terrestrial vegetation, some rip-rap, pondweed (*Potamogeton* sp.), coontail (*Ceratophyllum demersum*), cattail (*Typha* sp.), and water willow (*Justicia americana*). Twin Buttes Reservoir is composed of two pools with an equalization channel running between them. The south pool, which is significantly smaller than the north pool, is fed directly by the South Concho River from the south; the north pool is fed by Dove Creek and Spring Creek from the southwest, and the Middle Concho River from the northwest.

Water released from Twin Buttes Reservoir flows to the northeast into Lake Nasworthy, a 1,380-acre reservoir situated southwest of San Angelo. Lake Nasworthy is a shallow water body characterized by some rip-rap and mud banks; cattails (*Typha* sp.) and alligator weed (*Alternanthera philoxeroides*) are the primary vegetation types.

Water released from Lake Nasworthy reforms the South Concho River, which meanders northeast through the city of San Angelo before converging with the North Concho River, and continuing its flow east as the Concho River. There are 4 major pools, separated by dams, between Lake Nasworthy and the confluence of the North Concho and South

Concho Rivers: Metcalfe lake, Ben Ficklin Reservoir, Lone Wolf Reservoir, and Bell St. Reservoir (Figure 2).

O. C. Fisher Reservoir (5,440 acres) lies northwest of San Angelo and is fed by the North Concho River from the northwest. O. C. Fisher is characterized by rip-rap, mud banks, coontail (*Ceratophyllum demersum)*, and flooded terrestrial vegetation. Water released from O. C. Fisher Reservoir reforms the North Concho River until it's confluence with the South Concho River on the northeast side of the city of San Angelo (Figure 1).

Data Collection

TPWDIF donated fish that were collected during their surveys. *Pomoxis annularis* were collected from Twin Buttes Reservoir, Lake Nasworthy, O. C. Fisher Reservoir, and the South Concho River in the fall and winter of 2019 using trap nets. Trap nets are a passive sampling method designed to capture cover-dependent, mobile species of fish (Hubert et al., 2012). TPWDIF utilizes trap nets as the standard capture technique for both white crappie and black crappie (*Pomoxis nigromaculatus).* Ten nets were set on Twin Buttes Reservoir, 10 were set on the South Concho River, 5 were set on Lake Nasworthy, and 3 were set on O. C. Fisher Reservoir (Table 2). The number of nets deployed was relative to the overall size of the body of water; net locations were selected by TPWDIF. The trap nets were set and left for a 24-hour period. Thirty fish was deemed a desirable and significant sample size from each body of water so as not to negatively affect the population yet provide sufficient data for future analyses (Olden et al., 2002; Wisz et al., 2008). Donated fish were taken directly from the net until roughly 30 fish of varying size classes were obtained. Three size classes were predetermined using proportional size distribution (PSD) length categories: less than or equal to 12.7 cm (5 inches), between 12.7 and 25.4 cm (5 to 10 inches), and greater than or equal to 25.4 cm (Neumann et al., 2012).

Upon collection, fish specimens were returned to the lab and frozen in bags containing 2-3 individuals of similar size and weight. After thawing, individuals were identified with a dichotomous key (Hubbs et al., 2008), weighed (g), the length was measured (mm), and the fish was photographed. The necropsy procedure (Meyers, 2004) began with a visual inspection under a dissecting microscope for external parasites or abnormalities. The interior of the mouth was inspected for leeches or other external parasites. After inspecting the exterior and mouth, the gill isthmus was cut and the gills then removed and set into a dish of water. Next, the otic capsule was exposed and the otoliths were removed and saved for later analysis. Then, the fish was cut ventrally from the anus to the isthmus of the gills, and from the anus dorsally towards the dorsal fin to expose the viscera. The individual was sexed if the gonads were developed and visible. The organs were removed and set aside in a petri dish, then wet with Ringer's Solution. The intestine, stomach, pyloric caeca, liver, heart, spleen, and eyes were examined for parasites. The intestinal and stomach contents were also examined thoroughly for possible parasites. The heart, eyes, liver, and spleen were compressed between two small petri dishes and examined under the microscope. Nematodes were placed in glacial acetic acid to straighten them, and then transferred to 70% ethanol for storage. Next, the gills were examined for the presence of monogeneans. Gills were frozen for further analysis if monogeneans were found. A small sample of muscle tissue from each individual was frozen and labeled for future submission to the Angelo State Natural History Genomic Collection. The otoliths were examined under a dissecting microscope with a fiber optic light to determine the age of each individual in years.

The relative weight (Wr) of each fish was calculated to measure fish condition, and to determine the mean Wr for each water body (Neumann et al., 2012). Relative weight reports weight as a percentage of the predicted weight for a normal, healthy fish of a given length. A polynomial model was used to analyze correlation between host age and length. Statistical analysis was performed in R (r-project.org). Differences in mean host length between the 4 water bodies was analyzed using Welch's ANOVA after confirming all the assumptions of the test were met. Prevalence for each parasite species was calculated and compared across the water bodies using logistic regression. Pairwise logistic regressions were utilized as a posthoc test to identify differences in prevalence between water bodies was calculated using pairwise logistic regression. *P*-values from these pairwise tests were adjusted using the Holm method (Aickin and Gensler, 1996). When bootstrapped 95% confidence intervals were generated for prevalence, 10,000 iterations were used. Mean intensity for each parasite species was calculated for each water body. Differences in mean intensity between water bodies was analyzed using permutational ANOVAs (10,000 iterations) after confirming that all assumptions of the test were met. Pairwise permutational ANOVAs with Holm adjustment of *P*-values were performed as a post hoc test. Bootstrapped confidence intervals and standard error for the various measurements and statistics were not calculated for all age classes in all aquatic systems due to low sample size (<5) in some age classes.

RESULTS

Fish from ages 0 to 5-yr old were obtained from Lake Nasworthy, Twin Buttes Reservoir, O. C. Fisher Reservoir, and the South Concho River. Table 3 represents the number of individuals per age class obtained from each of the 4 bodies of water sampled. The mean ages of the host fish from the 4 water bodies are presented in Figure 3. Individuals from Lake Nasworthy had a mean age of 2.2 yr (SE 0.23), only 1-yr old fish were caught at O. C. Fisher Reservoir, Twin Buttes Reservoir had a mean age of 1.6 years (SE 0.29), and the South Concho River had a mean age of 1.6 years (SE 0.30). O. C. Fisher reservoir had the highest mean Wr of the 4 water bodies at 114.8% (SE 1.95). Lake Nasworthy, Twin Buttes Reservoir, and the South Concho River had mean Wr of 103.8% (SE 1.47), 99.2% (SE 1.47), and 98.3% (SE 3.85), respectively (Figure 4). Mean Wr by age class for the 4 water bodies sampled are shown in Figure 5. When age was accounted for in a linear model, lake was a significant predictor of Wr (Perm. ANOVA, $P<0.05$).

The length and age of sampled *P. annularis* were correlated (Figure 6, R^2=0.74). Welch's ANOVA determined that there was not a difference in mean host length between water bodies (Welch's ANOVA: $F_{3,54.65} = 2.80$, $P = 0.051$).

Four parasite species were recovered from the 113 necropsied *P. annularis*. *Cleidodiscus* sp. is a monogenean found on the gills of the fish. *Camallanus oxycephalus,* a nematode species, was recovered from the intestine and rectum. *Contracaecum* sp., also a nematode, was recovered from the intestine, mesenteries, and body cavity of the fish. Lastly, *Argulus longicaudus*, a crustacean, was recovered from the gills. Only one individual of *Argulus longicaudus* was recovered; the individual was from a fish collected at O. C. Fisher Reservoir.

Monogeneans were recovered from *P. annularis* from all 4 water bodies. Monogenean prevalence was 90% at the South Concho River, 61% at Twin Buttes Reservoir, 47% at Lake Nasworthy, and 41% at O. C. Fisher Reservoir (Figure 7). Monogenean prevalence varied by age within each body of water (Figures 8-10), but small sample sizes hindered statistical analysis. Prevalence at Lake Nasworthy was highest for age 0 and lowest for age 3. At the South Concho River, prevalence was 100% for ages 1-5 (n=18), and was 73% for age 0 individuals (n=11). For Twin Buttes Reservoir, prevalence was highest at age 2 and lowest at age 4.

Camallanus oxycephalus was recovered from Lake Nasworthy, Twin Buttes Reservoir, and the South Concho River. This parasite was not detected in O. C. Fisher. Prevalence was 94% for individuals from Lake Nasworthy, 14% for those from the South Concho River, and 4% for those from Twin Buttes Reservoir (Figure 11). Logistic regression revealed that there was a difference in prevalence between the 4 bodies of water. The prevalence of *C. oxycephalus* was significantly higher for Lake Nasworthy compared to other bodies of water (Pairwise logistic regression, $P_{adj}<0.05$). Mean intensity of *C. oxycephalus* was 3.58 (SE 0.791) for individuals from Lake Nasworthy, 1.33 (SE 0.333) for individuals from the South Concho River, and 1.0 for individuals from Twin Buttes Reservoir (Figure 12). *Camallanus oxycephalus* prevalence (Figure 13) and intensity (Figure 14) varied by age for Lake Nasworthy (logistic regression, $P<0.05$).

Contracaecum sp. was recovered in individuals from all 4 water bodies. *Contracaecum* sp. prevalence was 74% for fish from O. C. Fisher Reservoir, 43% for those from Twin Buttes Reservoir, 28% for those from the South Concho River, and 18% for those from Lake Nasworthy (Figure 15). A logistic regression revealed that there was a difference in prevalence between the 4 water bodies ($P<0.05$). The prevalence of *Contracaecum sp.* was significantly different between Lake Nasworthy and O. C. Fisher, and between O. C. Fisher and the South Concho River (Pairwise logistic regression, $P_{adj}<0.05$ for both comparisons). *Contracaecum* sp. intensity was 8.0 (SE 2.54) for fish from O. C. Fisher Reservoir, 3.1 (SE 0.690) for those from Twin Buttes Reservoir, 2.1 (0.701) for those from Lake Nasworthy, and 1.9 (0.423) for those from the South Concho River (Figure 16). *Contracaecum* sp. intensity did not significantly vary between water bodies (Perm. ANOVA, $P>0.05$).

DISCUSSION

Fish of varying age classes were obtained for each body of water (Table 3), the exception being O. C. Fisher Reservoir where only age 1 fish were collected. O. C. Fisher Reservoir recently dried and was restocked in 2015 when sufficient water levels returned. The reservoir is known to produce large *P. annularis* (BT, pers. obs) and it is possible that the older age classes were impacted by angling pressure, allowing a younger age class, age 1, to become increasingly abundant.

The 4 parasite species recovered from fish from Lake Nasworthy, O. C. Fisher Reservoir, Twin Buttes Reservoir, and the South Concho River have been documented in *P. annularis* previously. In a study of gill trematodes from Oklahoma fishes, Seamster (1938) reported the monogeneans *Cleidodiscus longus* and *Cleidodiscus vancleavei* in the gill tissue of infected *P. annularis* hosts. Both *C. longus* and *C. vancleavei* were reported in *P. annularis* by McGraw and Allyson (1967) in the Little River System of Texas. In a review of the helminth parasites from a lake in Ohio, Krueger (1954) also reported *C. longus* and *C. vancleavei* in the gills of infected *P. annularis* hosts. *Camallanus oxycephalus* is known to infect *P. annularis* in Texas (Gruninger, 1977); the adults are usually located in the intestine and rectum of the fish (Becker and Houghton, 1969; Spall, 1969). *Contracaecum* is a genus of ascarid nematodes. The larval stages are usually found in the intestine, body cavity, and in the mesenteries of infected Centrarchid hosts (Bangham, 1940, Stoyanov et al., 2018). *Contracaecum* sp. has been reported in *P. annularis* hosts in north Texas (Gruninger, 1977); *Contracaecum spiculigerum* has been reported in the Navasota River system and Little River system in east Texas (McGraw, 1964, Allison and McGraw, 1967). Three species in the subclass Copepoda were reported on *P. annularis* from Eagle Mountain Lake in North Texas, including *Argulus longicaudus* (Gruninger, 1977). These parasitic copepods are typically found adhering to or embedded in the gill filaments of infected hosts (Roberts, 1965, 1970).

Because of the difficulty of accurately counting individual monogeneans, prevalence was used to assess infection. Monogenean prevalence was highest in individuals from the South Concho River (Figure 7). These monogeneans have a direct life cycle, meaning they do not require an intermediate host to complete their life cycle. Monogeneans have a free-swimming larval stage and require fish-to-fish contact, or close proximity in order to achieve transmission (Kearn,1971). *Pomoxis annularis* were highly abundant in the South Concho River in 2019 (Wright, 2019). Perhaps the decreased surface acreage of the South Concho River, accompanied by an abundant *P. annularis* population, result in more efficient transmission for the parasite as opposed to a larger lake or reservoir (Samsing, 2014, Acosta et al., 2015).

Camallanus oxycephalus was highly prevalent in Lake Nasworthy for all age classes (Figure 13); individuals from Lake Nasworthy also had the highest intensity among the 4 water bodies (Figure 12). This parasite has a multi-host life cycle. The definitive host of *C. oxycephalus*, the host the parasite reproduces in, is a piscivorous fish, like *P. annularis*. The first stage larvae of the parasite are shed when gravid females protrude from the fish's anus and are exposed to freshwater (Stromberg and Crites, 1974). The first larval stage is found in copepods, which serve as the first intermediate host. The copepods are ingested by small planktivourous fish, like gizzard shad (Dorosoma cepedianum), which are then consumed by *P. annularis* to complete the life cycle. In regards to its gizzard shad population, Lake Nasworthy has a low index of vulnerability (IOV), meaning that a high percentage of the gizzard shad population is not vulnerable to predation by white crappie (Wright 2019).

Camallanus oxycephalus intensity peaked at age 1 and decreased with age (Figure 14). Similar to white crappie, gizzard shad are known to vary in their diet preferences with age; they feed on plankton early in life and transition to detritus over time (Yako et al., 2011). With increasing age and mouth gape, white crappie are likely selecting smaller gizzard shad early in life, and transitioning to larger gizzard shad over time. The smaller and younger gizzard shad that are prey for the younger age classes of white crappie are consuming are likely still planktivorous, and thus are more prone to consuming the copepods needed to complete the life cycle of *C. oxycephalus*. The decrease in *C. oxycephalus* intensity with age may reflect the transition in *P. annularis* diet to larger gizzard shad, which are likely feeding primarily on detritus.

Contracaecum sp. was highly prevalent in individuals collected from O. C. Fisher Reservoir; *Contracaecum* sp. mean intensity was also highest in fish from O. C. Fisher. Like *C. oxycephalus*, *Contracaecum* sp. has a multi-host life cycle (Huizinga, 1967). Huizinga (1966) described the life cycle of *Contracaecum spiculigerum*. The definitive host is a pisciverous bird, such as a cormorant (Family Phalacrocoracidae). The eggs are shed in the feces of the bird, hatch to a free-living, second-stage larvae. The infective second stage larvae are either consumed by copepods or directly by a planktivorous fish. If a copepod consumes the second stage larvae, then that infected copepod must be ingested by small planktivorous fish, such as a gizzard shad, which are in turn consumed by a pisciverous fish, like *P. annularis*. The pisciverous fish host may be activating as a paratenic host and transmit the parasite to the piscivorous bird, completing the life cycle. The transmission from second stage larvae to the fish and then to the bird is not as successful as the route including copepods as an intermediate host. In fish from Twin Buttes Reservoir, *Contracaecum* sp.

prevalence increased with age (Figure 17). This pattern is likely a product of time and older fish consuming more prey items than younger individuals. Consuming increased quantities of gizzard shad as the fish ages exposes it to more *Contracaecum* sp. larvae. This increases the chance of transmitting the parasite from gizzard shad to white crappie. In a study from Garner Lake in Alberta, Canada, Zelmer and Arai (1998) reported older yellow perch (*Perca flavescens*) having more parasite species and larger parasite infrapopulations than younger individuals; however, *Contracaecum* sp. was not observed in their study.

CONCLUSION

Aside from Twin Buttes Reservoir, each of the water bodies sampled had a parasite species that was more prevalent and had a higher intensity in *P. annularis* than the other 3. Fish from the South Concho River revealed the highest prevalence for monogeneans, *C. oxycephalus* was dominant in Lake Nasworthy, and *Contracaecum* sp. was dominant in O. C. Fisher Reservoir.

With Twin Buttes Reservoir, Lake Nasworthy, and the South Concho River situated downstream of one another, it is presumable to expect to see a nested downstream accumulation effect in parasites. If a parasite species is detected in a body of water upstream, it should be found in those downstream with increasing abundance and rates of infection (Blasco-Costa et al., 2013). No accumulation pattern was observed as each differed in their dominant parasite species. Each water body inevitably possesses different water quality parameters that in turn affect primary productivity and the biomass that can be supported. Likewise, each water body has varying abundances of prey and predator species that influence the parasite communities observed in *P. annularis* (Marcogliese, 2002). Finally, our sample represented a single time point in a year. If parasite transmission varies seasonally, then perhaps as accumulation effect would be seen during seasons with high parasite transmission.

The rates of infection for each parasite species recovered vary with age and water body. Diet preference is likely a key factor in predicting prevalence or intensity with age in *P. annularis.* Other freshwater gamefish in West Texas, such as white bass or walleye, may exhibit similar infection rate patterns as a result of diet shifts from zooplanktivory to piscivory as the host ages (Michaletz et al., 1987). This work provides a template for future research comparing host age and parasite community association, as well as work centered on documenting parasite communities of freshwater fishes in West-Central Texas.

LITERATURE CITED

Acosta, A. A., J. Queiroz, H. Brandao, and J. R. Silva. 2015. Helminth fauna of *Astyanax fasciatus* Cuvier, 1819, in two distinct sites of the Taquari River, São Paulo State, Brazil. Brailian Journal of Biology 75: 242-250.

Aickin, M., and H. Gensler. 1996. Adjusting for multiple testing when reporting research results: the Bonferroni vs Holm methods. American Journal of Public Health 86: 726-728.

Bangham, R. V. 1940. Parasites of fresh-water fish of southern Florida. Proceedings of the Florida Academy of Sciences 5: 289-307.

Becker, D. A., and W. C. Houghton. 1969. Survey of the helminth parasites of selected game fishes of Lake Fort Smith, Arkansas. Journal of the Arkansas Academy of Science 23: 110-117.

Blasco-Costa, I., A. V. Koehler, A. Martin, and R. Poulin. 2013. Upstream-downstream gradient in infection levels by fish parasites: a common river pattern? Parasitology 140: 266-274.

Burris, W.E. 1956. Studies of age, growth, and food of known-age and young-of the-year black crappie and of stunted and fast growing black and white crappies of some Oklahoma lakes. Doctoral dissertation, Oklahoma Agriculture and Mechanical College, Stillwater, OK. 88pp.

Crawley, H. D. 1954. Causes of stunting of crappie *Pomoxis nigromaculatus* and *Pomoxis annularis* in Oklahoma lakes. Doctoral dissertation. Oklahoma Agriculture and Mechanical College, Stillwater, OK. 94pp.

Edwards, E. A., D. A. Krieger, G. Gebhart, and O. E. Maughan. 1982. Habitat suitability index models: white crappie. U.S.D.I. Fish and Wildlife Service. FWS/OBS-82/10.7. 22pp.

Gruninger, T. L., C. E. Murphy, and J. C. Britton. 1977. Macroparasites of fish from Eagle Mountain Lake, Texas. The Southwestern Naturalist 22: 525-535.

Hansen, D. F. 1951. Biology of the white crappie in Illinois. Illinois National History Survey Bulletin 29: 209-265.

Hubbs, C., R. J. Edwards, and G. P. Garrett. 2008. An annotated checklist of the freshwater fishes of Texas, with keys to identification of species, 2nd Edition. Texas Academy of Science. p. 43-44

Hubert, W. A., K. L. Pope, and M. J. Dettmers. 2012. Passive capture techniques. *In* Fisheries techniques, 3rd edition. A. V. Zale, D. L. Parish, and T. M. Sutton (eds.) American Fisheries Society. p. 223-253.

Huizinga, H. W. 1966. Studies on the life cycle and development of *Contracaecum spiculigerum* (Rudolphi, 1809)(Ascaroidea: Heterocheilidae) from marine piscivorous birds. Journal of the Elisha Mitchell Scientific Society 82: 181-195.

Huizinga, H. W. 1967. The life cycle of *Contracaecum multipapillatum* (von Drasche, 1882) Lucker, 1941 (Nematoda: Heterochelidae). The Journal of Parasitology. 53: 368-375

Kaczka, L. J., and L. E. Miranda. 2014. Size of age-0 crappies (*Pomoxis* spp.) relative to reservoir habitats and water levels. Journal of Freshwater Ecology 29: 525-534.

Kearn, G. C. 1971. The attachment site, invasion route and larval development of *Trochopus pini*, a monogenean from the gills of *Trigla hirundo.* Parasitology 63: 513-525

Krueger, R. F. 1954. A survey of the helminth parasites of fishes from Van Buren Lake and Rocky Ford Creek. The Ohio Journal of Science 54: 277.

Marcogliese, D. L. 2002. Food webs and the transmission of parasites to marine fish. Parasitology 124: 83-99.

Mayberry, L. F., A. G. Canaris, J. R. Bristol, and S. L. Gardner. 2000. Bibliography of parasites and vertebrate hosts in Arizona, New Mexico and Texas (1893–1984). Faculty Publications from the Harold W. Manter Laboratory of Parasitology. 2.

McGraw, J.L. 1964. Some internal helminth parasites of certain Centrarchidae of the Navasota and Little Rivers of Texas. M.S. Thesis, Texas A&M University, College Station, TX.

McGraw, J. L., and T. C. Allison. 1967. Helminth parasites of Centrarchidae of the Little River system of Texas. The Southwestern Naturalist 12: 332-333.

Meyers, T. R. 2004. Standard necropsy procedures for finfish. *In* NWFHS Laboratory Procedures Manual, 2nd edition. Chapter 4. pp. 1-10.

Michaletz, P. H., D. G. Unkenholz, and C. C. Stone. 1987. Prey size selectivity and food partitioning among zooplanktivorous age-0 fishes in Lake Francis Case, South Dakota. The American Midland Naturalist 117: 126-138.

Neumann, R. M., C. S. Guy, and D. W. Willis. 2012. Length, weight, and associated indices. *In* Fisheries techniques, 3rd edition. A. V. Zale, D. L. Parish, and T. M. Sutton (eds.) American Fisheries Society. p. 637-676.

Olden, J. D., D. A. Jackson, and P. R. Peres-Neto. 2002. Predictive models of fish species distributions: a note on proper validation and chance predictions. Transactions of the American Fisheries Society 131: 329-336.

Roberts, L. S. 1965. *Ergasilus tenax* sp. n. (Copepoda: Cyclopoida) from the white crappie, *Pomoxis annularis* Rafinesque. The Journal of Parasitology 51: 987-989.

Roberts, L. S. 1970. *Ergasilus* (Copepoda: Cyclopoida): revision and key to species in North America. Transactions of the American Microscopical Society 89: 134-161.

Samsing, F., F. Oppedal, D. Johansson, Bui, S., and T. Dempster. 2014. High host densities dilute sea lice *Lepeophtheirus salmonis* loads on individual Atlantic salmon, but do not reduce lice infection success. Aquaculture Environment Interactions 6: 81-89.

Spall, R. D. 1969. The endoparasitic helminths of fishes from Lake Carl Blackwell, Oklahoma. Proceedings of the Oklahoma Academy of Science for 1968. 91-99pp.

Spall, R. D., and R. C. Summerfelt. 1969. Host-parasite relations of certain endoparasitic helminths of the channel catfish and white crappie in an Oklahoma reservoir. Bulletin of the Wildlife Disease Association 5: 48-67.

Stoyanov, B., Y. Mutafchiev, P. Pankov., and B. B. Georgiev. 2018. Helminth parasites in the alien *Lepomis gibbosus* (L.) (Centrarchidae) from the Lake Atanasovsko Wetlands, Bulgaria: Survey of species and structure of helminth communities. Acta Zoologica Bulgarica 70: 1-20.

Stromberg, P. C., and J. L. Crites. 1974. The life cycle and development of *camallanus oxycephalus* Ward and Magath, 1916 (Nematoda: Camallanidae). The Journal of Parasitology 60: 117-124.

Wisz, J. D., R. J. Hijmans, J. Li, A. T. Peterson, C. H. Graham, and A. Guisan. 2008. Effects of sample size on the performance of species distribution models. Diversity and Distr2111111ibutions 14: 763-773.

Wright, L. D. 2019. Statewide freshwater fisheries monitoring and management program survey report for Nasworthy Reservoir, 2018. Texas Parks and Wildlife Department, Federal Aid Report F-221-M-3, Austin TX.

Wright, L. D. 2019. Statewide freshwater fisheries monitoring and management program survey report for the South Concho River, 2019. Texas Parks and Wildlife Department, Federal Aid Report F-221-M-3, Austin, TX.

Yako, L. A., J. M. Dettmers, and R. A. Stein. 2011. Feeding preferences of omnivorous gizzard shad as influenced by fish size and zooplankton density. Transactions of the American Fisheries Society 125: 753-759.

Zelmer, D. A., and H. P. Arai. 1998. The contributions of host age and size to the aggregated distribution of parasites in yellow perch, *Perca flavescens*, from Garner Lake, Alberta, Canada. The Journal of Parasitology 84: 24-28.

APPENDIX

Table I. Reported parasite species of *Pomoxis annularis* in Texas (Mayberry, 2000) and location in infected hosts. N.R. = Not Reported.

Taxon	Parasite Species	Adult/Larval	Location in *P. annularis*
Cestoda	*Proteocephalus amblopliti*s	Adult	Gonads, Liver
Cestoda	*Proteocephalus ambloplitis* plerocercoid	Larval	Gonads, liver
Trematoda	*Caecincola parvulus*	Adult	Intestine
Trematoda	*Cleidodiscus longus*	Adult	Gills
Trematoda	*Cleidodiscus uniformis*	Adult	Gills
Trematoda	*Cleidodiscus vancleavei*	Adult	Gills
Trematoda	*Clinostomum marginatum*	Larval	Intestine
Trematoda	*C. marginatum* Metacercariae	Larval	Musculature
Trematoda	*Crepidostomum cooperi*	Adult	Intestine
Trematoda	*Phyllodistomum lohrenzi*	Larval	Urinary bladder
Trematoda	*Pisciamphistoma reynoldsi*	N.R.	N.R.
Trematoda	*Posthodiplostomum minimum*	Larval	Heart, liver, spleen, kidney, mesenteries
Nematoda	*Camallanus oxycephalus*	Larval	Intestine, Rectum
Nematoda	*Contracaecum*	Larval	Intestine, mesenteries, and body cavity
Nematoda	*Contracaecum spiculigerum*	Larval	Intestine, mesenteries, and body cavity
Nematoda	*Spinitectus carolini*	Larval	Pyloric caeca, Intestinal tract
Acanthocephala	*Eocollis arcanus*	N.R.	Intestine
Acanthocephala	*Neoechinorhynchus constrictus*	N.R.	Intestine

Table I. Continued

Crustacea	*Argulus longicaudus*	Adult	Gills
Crustacea	*Ergasilus tenax*	Adult	Gills
Crustacea	*Lernaea cyprinacaea*	Adult	Gills

Table II. The number of nets set and *Pomoxis annularis* collected and donated from each body of water.

Body of Water	**Number of Nets**	**# of *Fish* Collected**
Twin Buttes	10	23
Lake Nasworthy	5	34
O. C. Fisher	3	27
S. Concho River	10	29

Table III. Number of *Pomoxis annularis* per age class from Lake Nasworthy (NW), O. C. Fisher Reservoir (OC), Twin Buttes Reservoir (TB), and the South Concho River (SC).

Lake	**Age**					
	0	**1**	**2**	**3**	**4**	**5**
NW	1	12	10	4	4	3
OC	0	27	0	0	0	0
TB	8	3	5	5	2	0
SC	11	5	5	4	2	2

Figure 1. Map of the primary bodies of water in Tom Green County, TX.

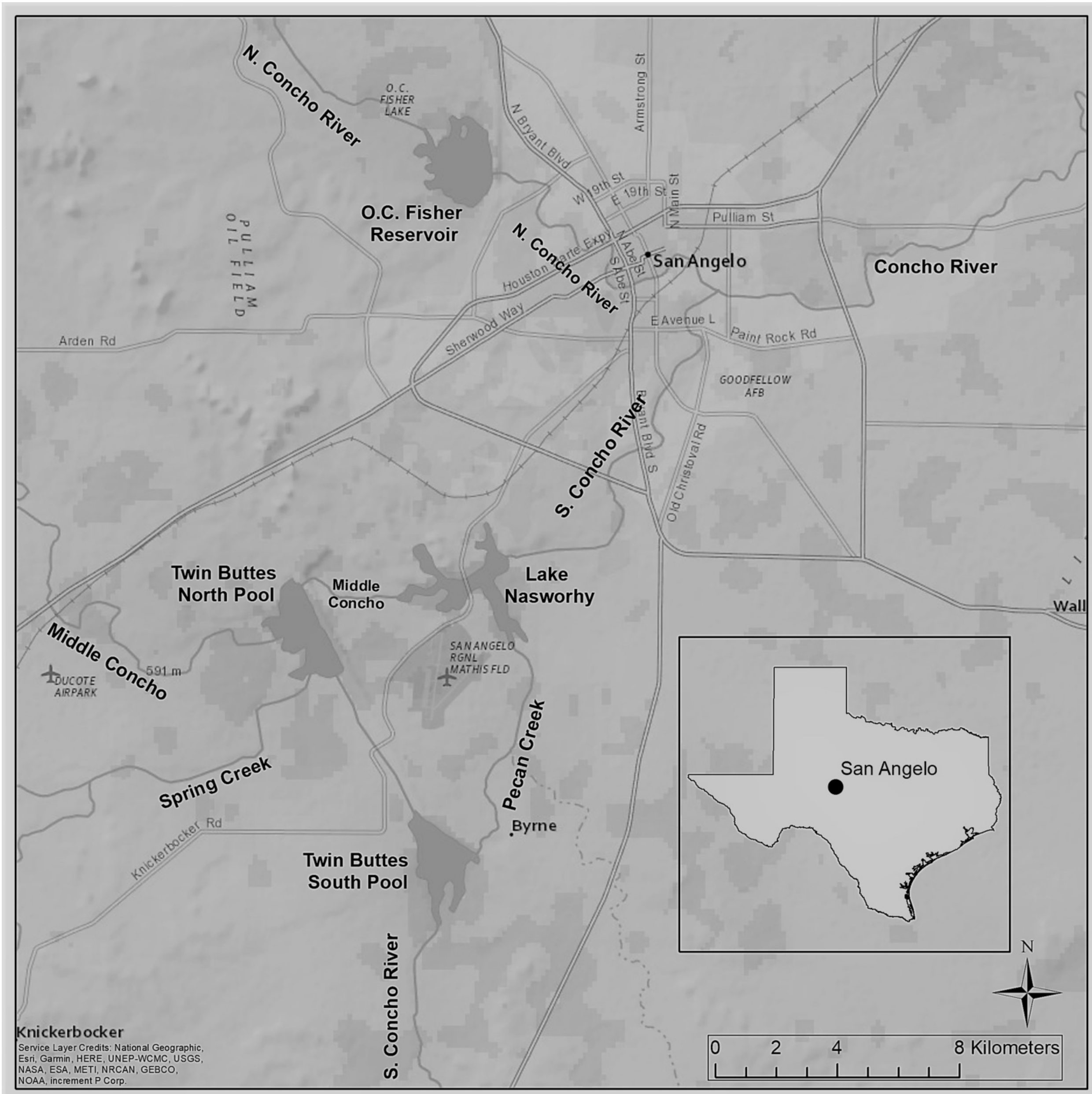


Figure 2. Map of the 4 lakes and reservoirs of the North and South Concho Rivers in San Angelo, TX.

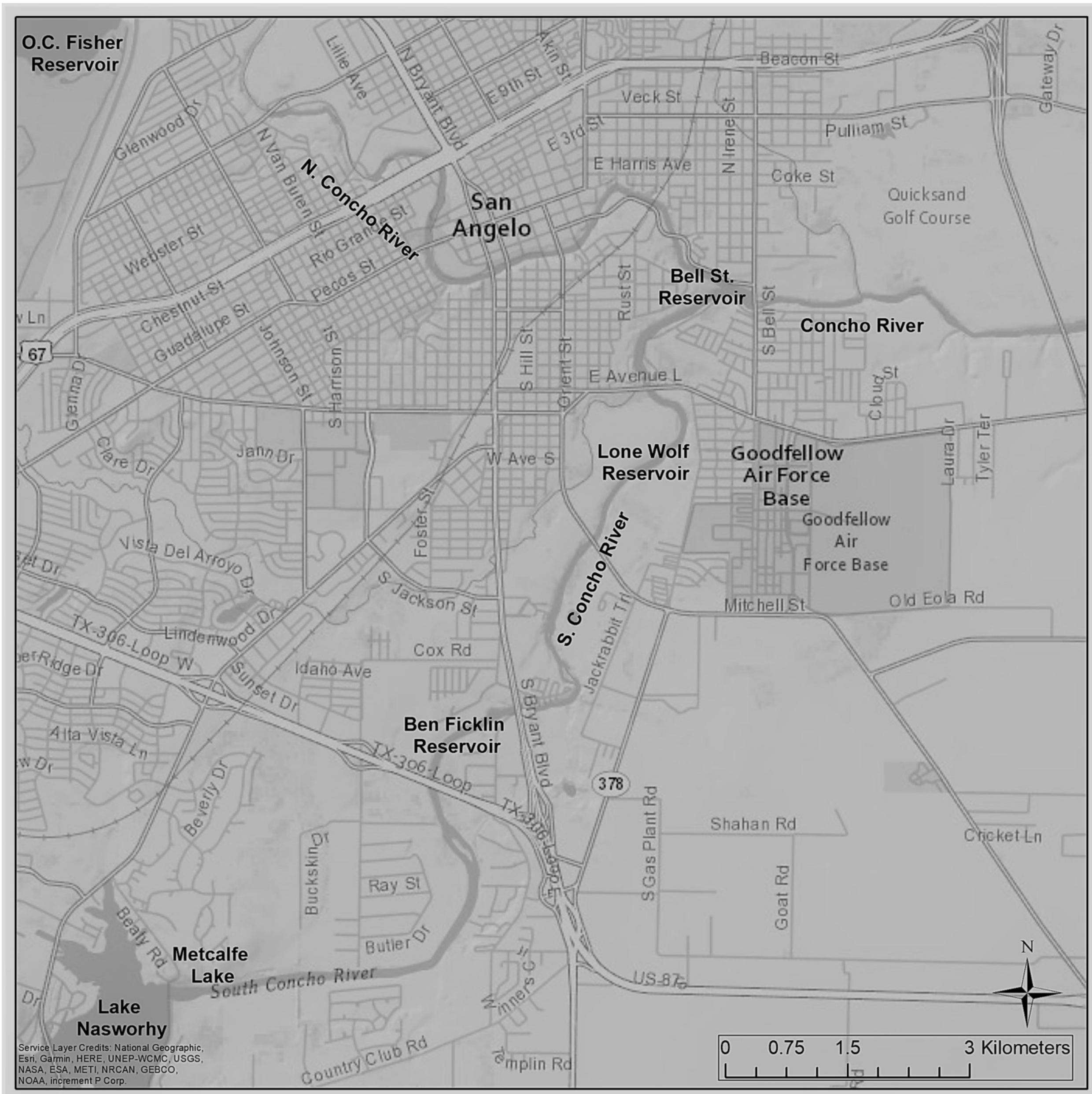


Figure 3. Mean (±SE) *Pomoxis annularis* age for Lake Nasworthy (NW, n=34), O. C. Fisher Reservoir (OC, n=27), Twin Buttes Reservoir (TB, n=23), and the South Concho River (SC, n=29).

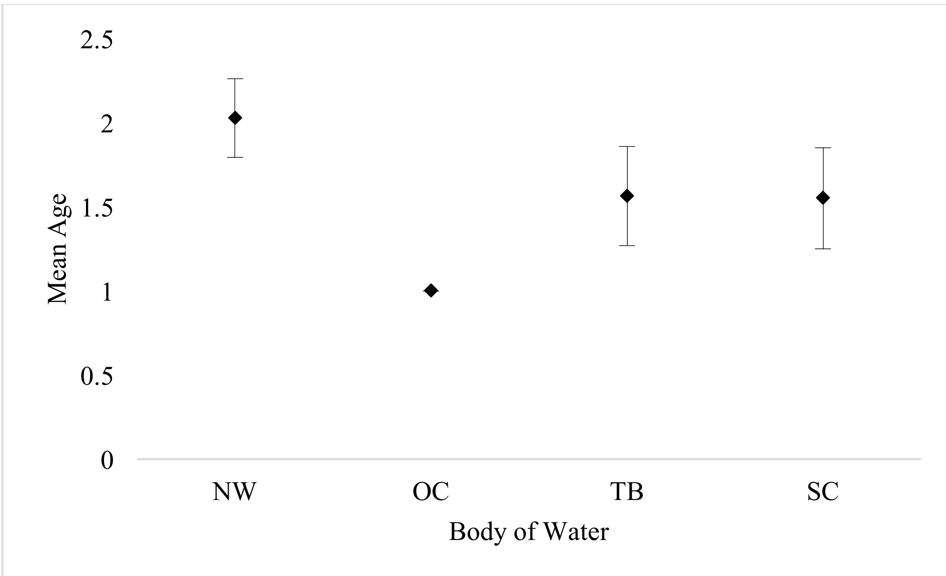


Figure 4. Mean relative weight of *Pomoxis annularis* for Lake Nasworthy (NW, n=34), O. C. Fisher Reservoir (OC, n=27), Twin Buttes Reservoir (TB, n=23), and the South Concho River (SC, n=29).

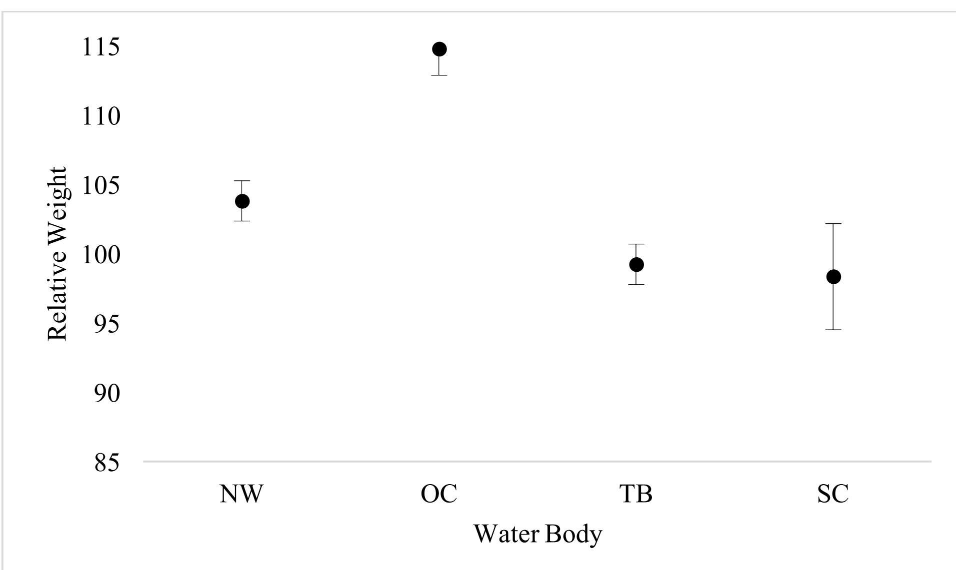


Figure 5. Mean relative weight for *Pomoxis annularis* by age for Lake Nasworthy (NW, n=34), O. C. Fisher Reservoir (OC, n=27), Twin Buttes Reservoir (TB, n=23), and the South Concho River (SC, n=29).

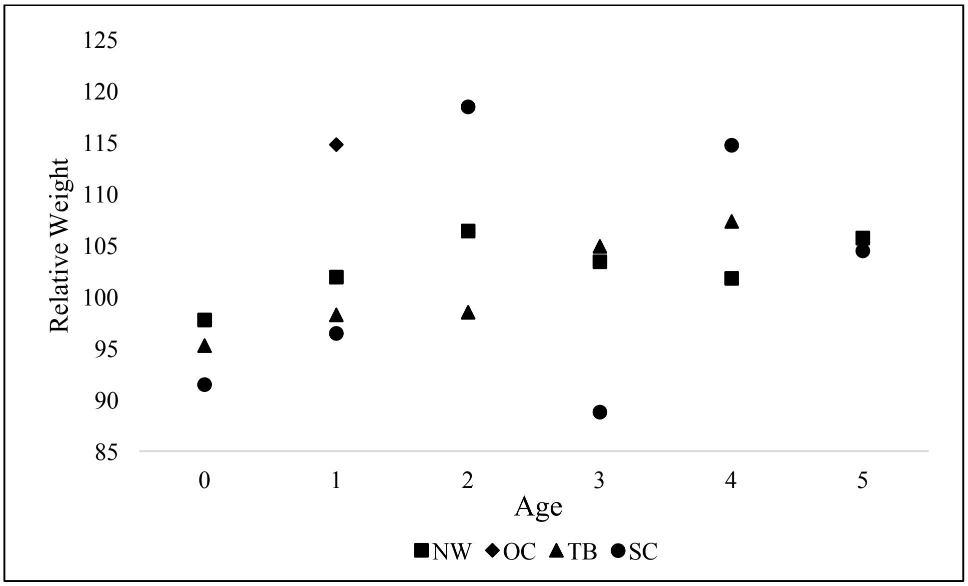


Figure 6. The length (mm) and age of the *Pomoxis annularis* hosts (n=113) were correlated (R^2 = 0.74).

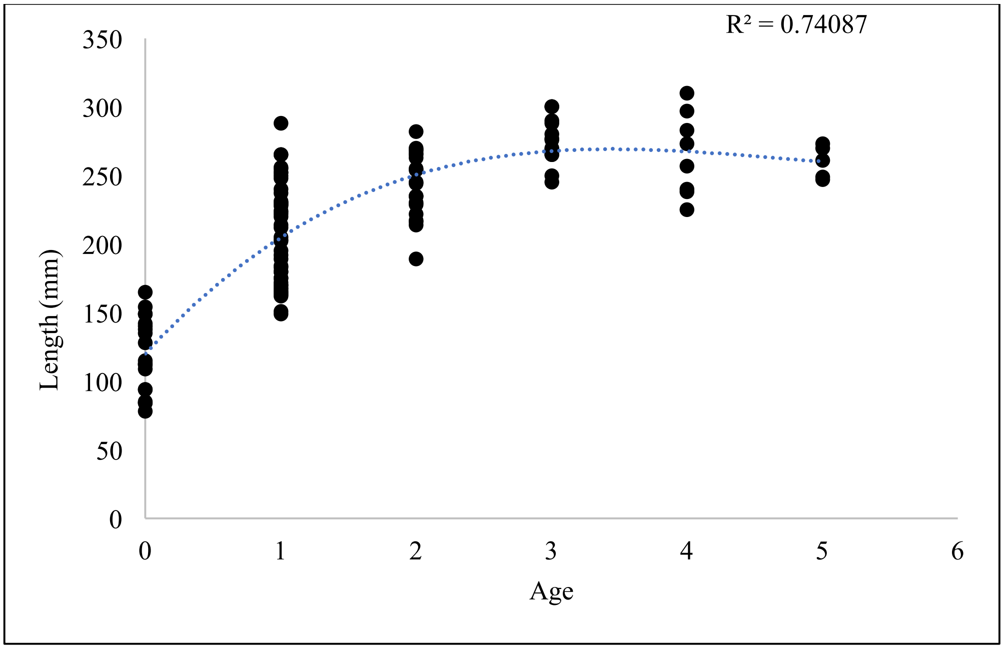


Figure 7. Monogenean prevalence of *Pomoxis annularis* for Lake Nasworthy (NW, n=34), O. C. Fisher Reservoir (OC, n=27), Twin Buttes Reservoir (TB, n=23), and the South Concho River (SC, n=29), with bootstrapped 95% confidence intervals.

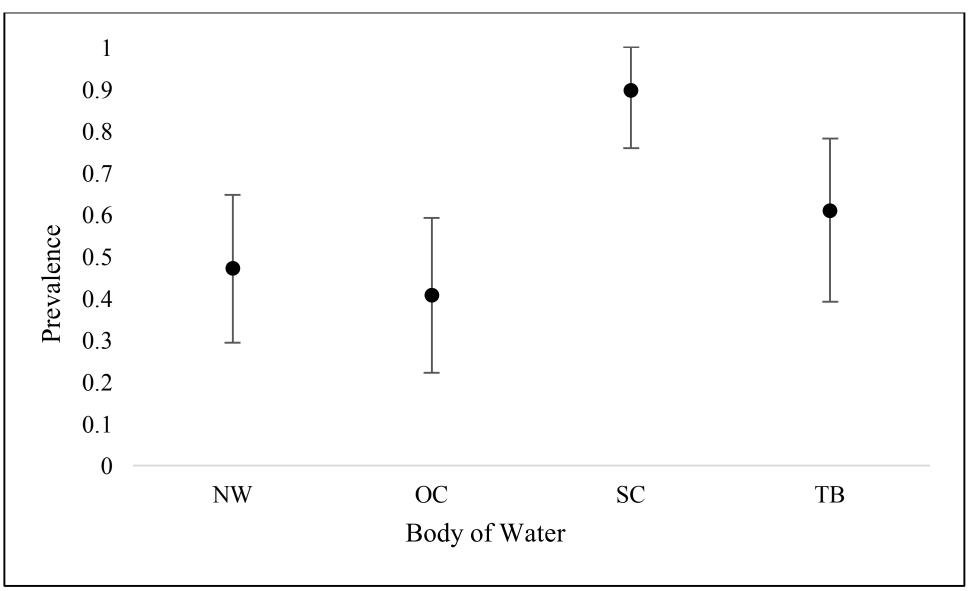


Figure 8. Monogenean prevalence by *Pomoxis annularis* age for Lake Nasworthy. Prevalence was highest at age 0 (n=1), and lowest at age 3 (n=4). Bootstrapped 95% confidence intervals were not calculated because of the small sample size within each age category.

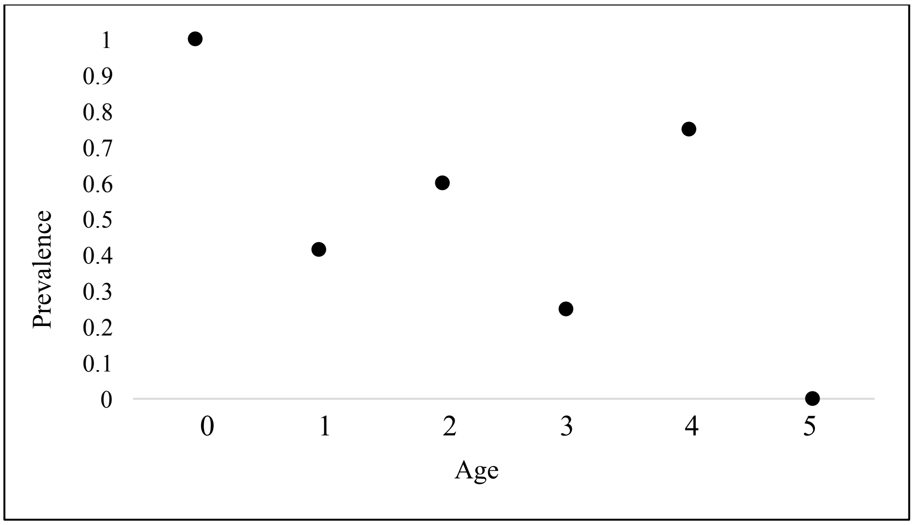


Figure 9. Monogenean prevalence by *Pomoxis annularis* age for the South Concho River. Prevalence was 1.0 for ages 1-5 (n=18), and was lowest at age 0 (n=11). Bootstrapped 95% confidence intervals were not calculated because of the small sample size within each age category.

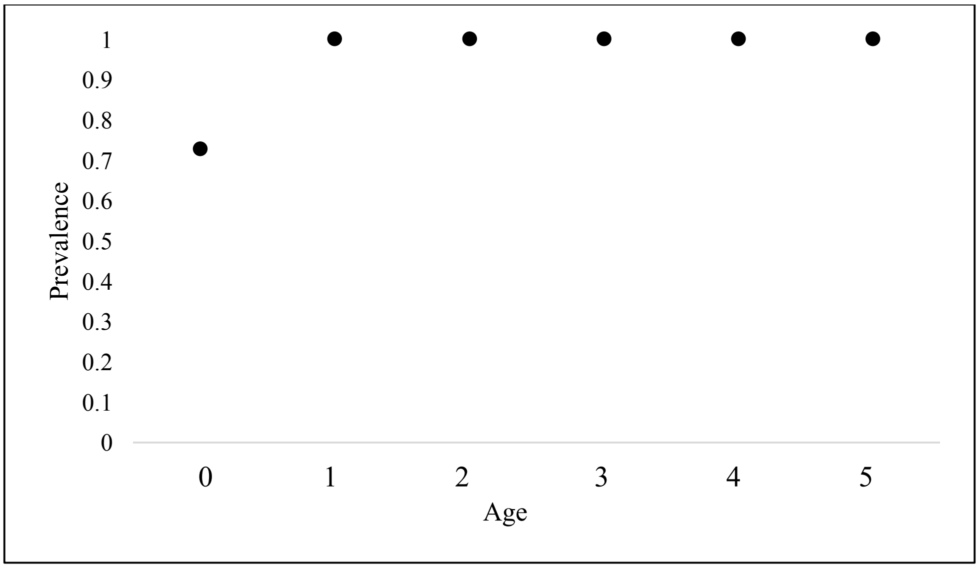


Figure 10. Monogenean prevalence by *Pomoxis annularis* age for Twin Buttes Reservoir. Prevalence was highest at age 2 (n=5), and lowest at age 4 (n=2). Bootstrapped 95% confidence intervals were not calculated because of the small sample size within each age category.

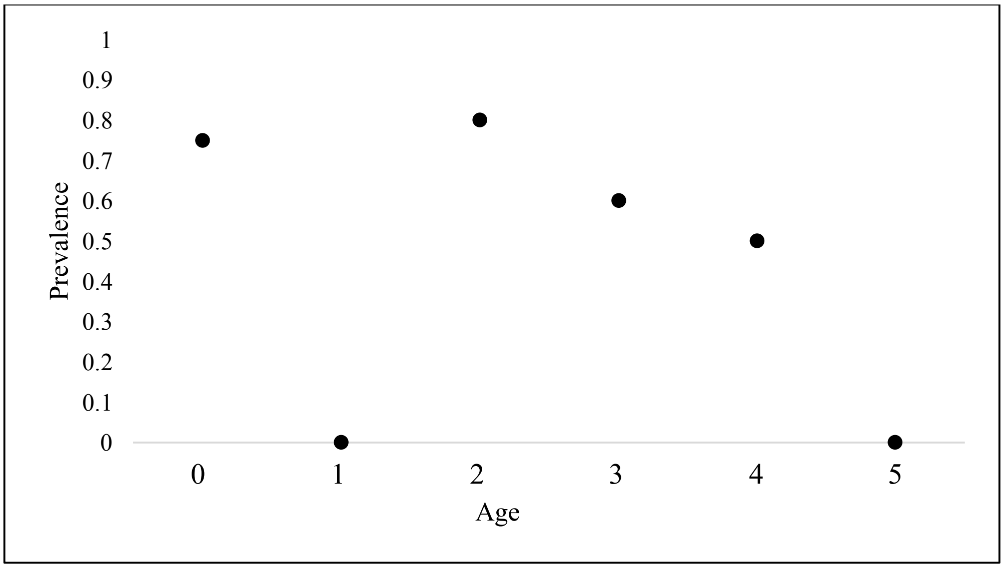


Figure 11. *Camallanus oxycephalus* prevalence for *Pomoxis annularis* in Lake Nasworthy (NW, n=34), O. C. Fisher Reservoir (OC, n=27), Twin Buttes Reservoir (TB, n=23), and the South Concho River (SC, n=29), with bootstrapped 95% confidence intervals.

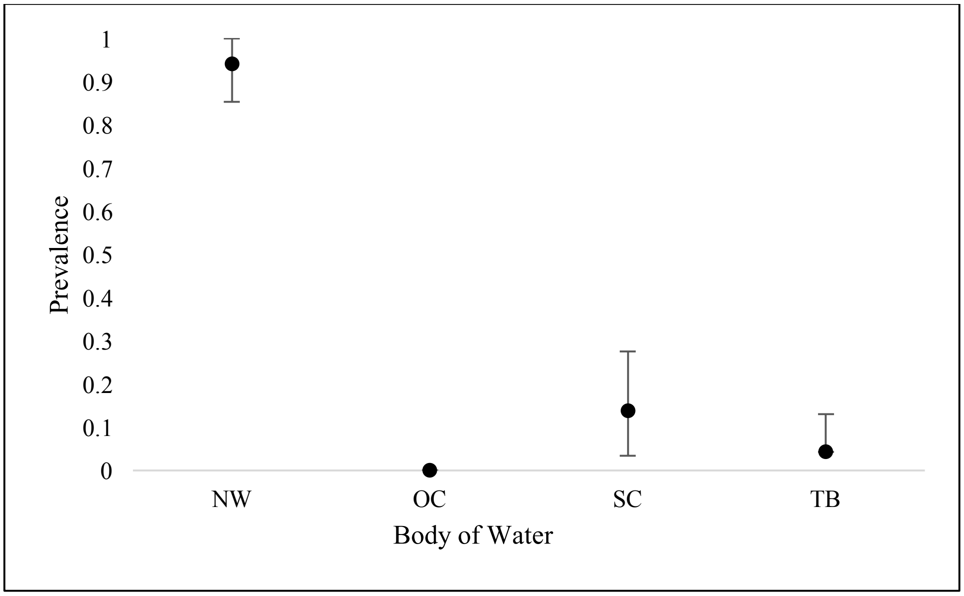


Figure 12. Mean (±SE) intensity for *Camallanus oxycephalus* in *Pomoxis annularis* Lake Nasworthy (NW, n=34), O. C. Fisher Reservoir (OC, n=27), Twin Buttes Reservoir (TB, n=23), and the South Concho River (SC, n=29). Intensity was highest for individuals from Lake Nasworthy and lowest from individuals from Twin Buttes Reservoir. This parasite was not detected in O. C. Fisher Reservoir.

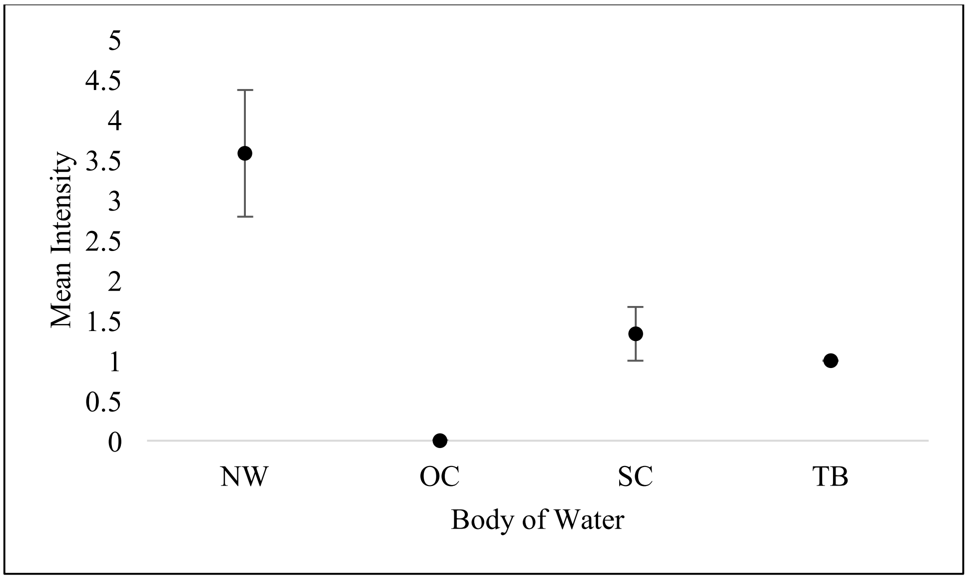


Figure 13. *Camallanus oxycephalus* prevalence for *Pomoxis annularis* from Lake Nasworthy. Bootstrapped 95% confidence intervals were not calculated because of the small sample size within each age category.

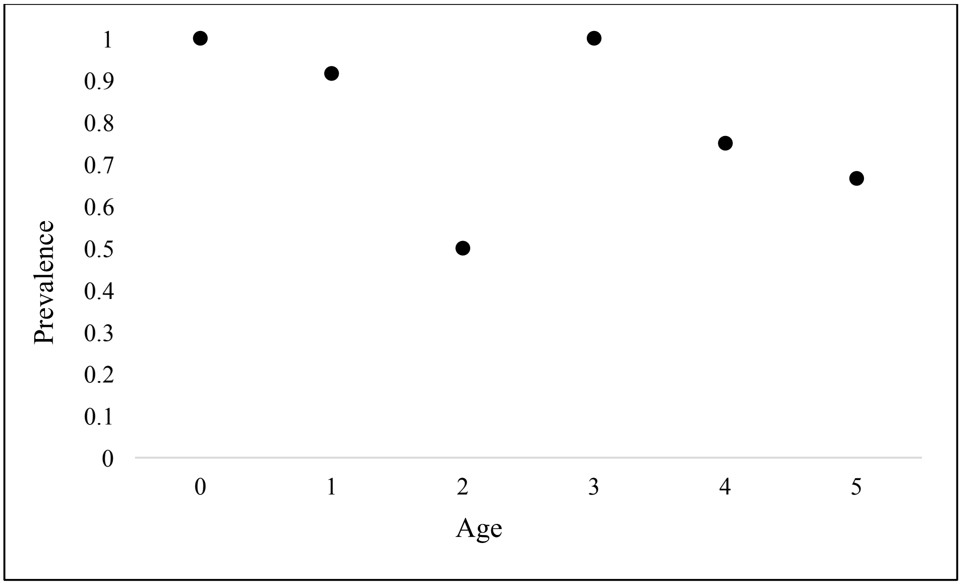


Figure 14. *Camallanus oxycephalus* mean intensity for *Pomoxis annularis* from Lake Nasworthy.

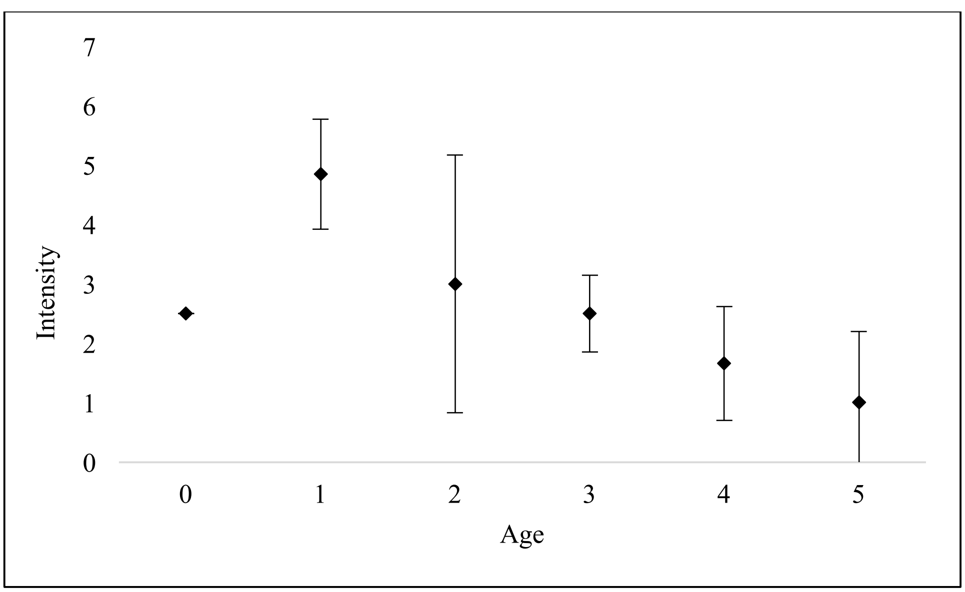


Figure 15. *Contracaecum* sp. prevalence for *Pomoxis annularis* in Lake Nasworthy (NW, n=34), O. C. Fisher Reservoir (OC, n=27), Twin Buttes Reservoir (TB, n=23), and the South Concho River (SC, n=29), with bootstrapped 95% confidence intervals.

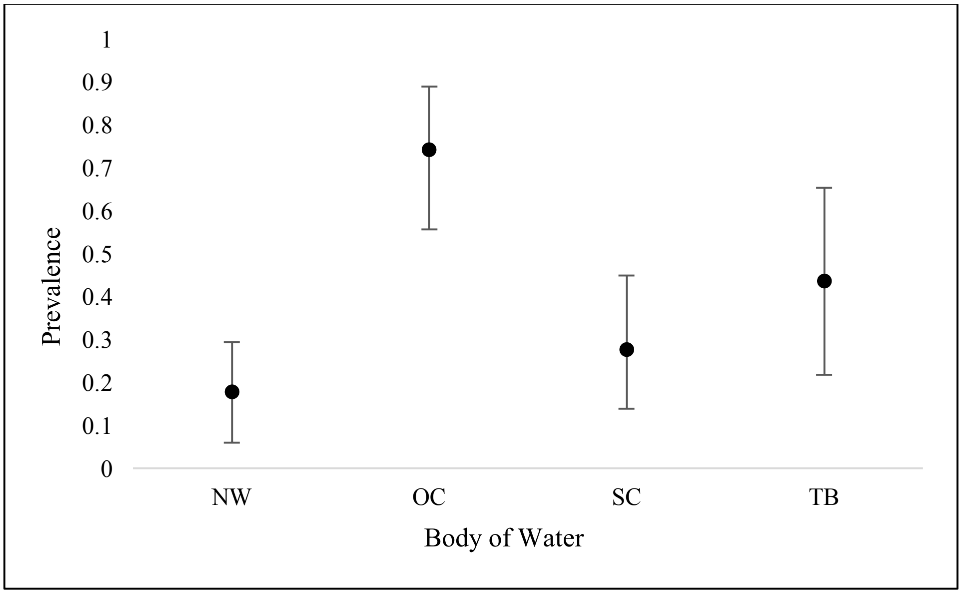


Figure 16. *Contracaecum* sp. mean intensity (±SE) for *Pomoxis annularis* in Lake Nasworthy (NW, n=34), O. C. Fisher Reservoir (OC, n=27), Twin Buttes Reservoir (TB, n=23), and the South Concho River (SC, n=29).

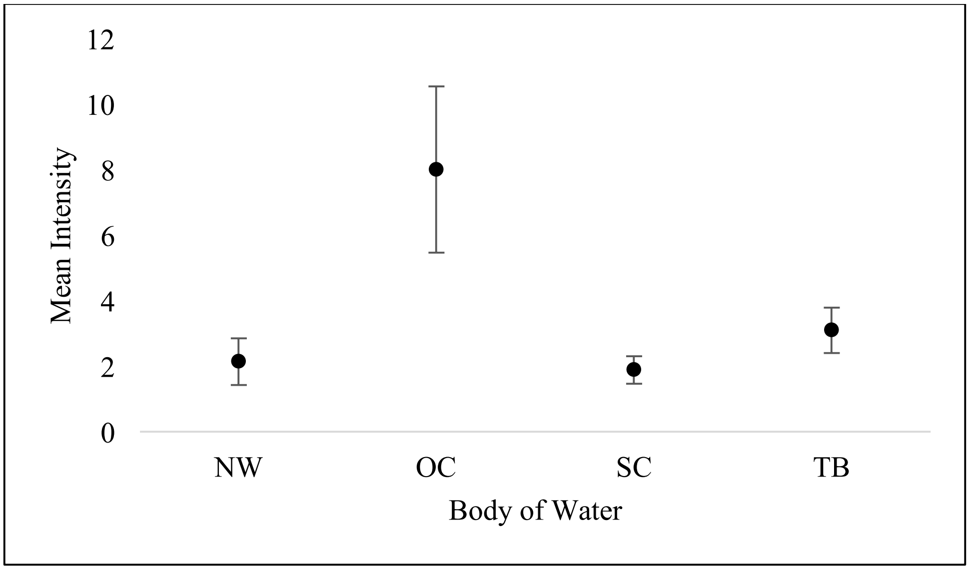
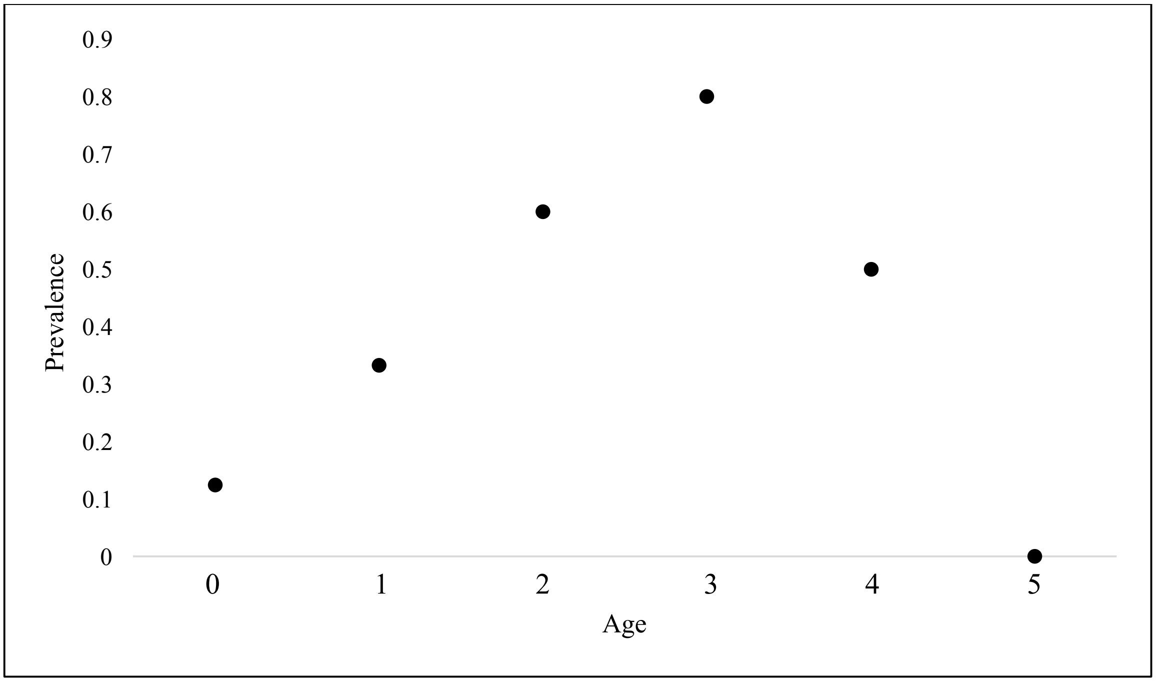


Figure 17. *Contracaecum* sp. prevalence for *Pomoxis annularis* from Twin Buttes Reservoir. Bootstrapped 95% confidence intervals were not calculated because of the small sample size within each age category.



VITA

Blake Price Thornton attended Lubbock Christian University from August 2014 to December 2018 where he completed his Bachelor of Science with a major in Natural Resources, Ecology, and Conservation. Following graduation, he moved to San Angelo, TX, to continue his education as a master's student at Angelo State University. He attended ASU from August 2019 to May 2021 and completed his Master of Science degree in Biology. His major field of specialization was fish parasitology, where he developed skills in fish necropsy, and handling and preparing parasite specimens. Blake can be reached by email at bthornton@lochowranch.com